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Research Paper

The response of benthic macroinvertebrate communities to climate change: evidence from subtropical mountain streams in Central China

key words: climate change, north subtropical monsoon, ENSO, water temperature, water flow, benthic macroinvertebrate, biodiversity

Abstract

Ecological effects of climate change on terrestrial and marine ecosystems are increasingly apparent but evidence from freshwater is scarce, particularly in Asia. Using data from two subtropical Central China streams, we predicted the changes of some benthic macroinvertebrate communities under various climatic scenarios. Our results show that the average annual air temperature, in the study watershed, increased significantly \((P < 0.05)\) by 0.6 °C over the last 30 years (1978–2007), whereas the average annual water flow declined by 30.9 m³ s⁻¹. Based on the winter sampling of benthic macroinvertebrates at four stream locations over last six years, we observed that macroinvertebrate abundance and Margalef diversity dropped with increasing water temperatures or decreasing smoothed sea surface temperatures (SSST). The winter macroinvertebrate abundance and biodiversity declined by 11.1% and 6.8% for every 1 °C water temperature rise. In contrast, increases in future SSST by one unit would increase winter macroinvertebrate abundance and biodiversity by 38.2% and 16.0%, respectively. Although many dominant taxa were predicted to persist when water temperatures increase by 1 °C, several scarce taxa, e.g., Orthocladius clarkei and Hippeutis umbilicalis, could be at a level of potential local extinction.

Our identification of these links, between climate change and stream macroinvertebrate communities, has wide implications for the conservation of mountain stream ecosystems in the upper Yangtze River under scenarios of climate change.

1. Introduction

Climate change poses a considerable threat to biodiversity all over the world, especially at high latitudes and altitudes (BROWN et al., 2007). Early research on climate change focused on alterations in temperature, rainfall, and the extent of glaciers or snowpacks (BARNETT et al., 2005; BROWN et al., 2007; DURANCE and ORMEROD, 2007). Since the 1990s, the relationship between climate change and biodiversity conservation has attracted increasing attention because of the potential influence of climatic fluctuations on global ecosystems and regional
biodiversity (Daufresne et al., 2004; Harte et al., 2004; Thomas et al., 2004). Streams play an important role in the hydrological cycle and the biogeochemistry of nutrients, linking terrestrial to aquatic ecosystems, and provide many resources for human use (Vannote et al., 1980; Naïman and Bilby, 2001). However, we cannot develop an effective conservation strategy if we do not have the knowledge about the impacts of climate warming on stream organisms. Therefore, we need to assess the influence of climate warming on stream ecosystems.

The two main aspects of climatic impacts on streams are water temperature and water flow (Durance and Ormerod, 2007). The importance of water temperature has long been recognized as a major factor determining the distribution and richness of stream organisms along gradients of latitude and altitude (Vannote et al., 1980; Quinn and Hickey, 1990; Reyjol et al., 2001). Water temperature has large effects on the embryonic development, larval growth, emergence, metabolism and survivorship of stream taxa (Marchant and Hehir, 1999; Haidekker and Hering, 2008). Temperature can also influence production, consumption, and decomposition in stream ecosystems with consequences for ecological energy (Richardson, 1992). Furthermore, global warming can have large effects on regional rainfall patterns by disturbing the current atmospheric circulation patterns, altering the global and regional hydrothermal conditions, and ultimately increasing the frequency and intensity of droughts and floods (Stewart et al., 2004; Mote et al., 2005). Changes of water flow can influence water quality, stream channel morphology and stability, and indirectly the composition and dynamics of freshwater communities (Lake, 2000; Milner et al., 2001; Lytle and Poff, 2004). In our study we also consider the El Niño Southern Oscillation (ENSO) as a kind of climatic variable because, although ENSO occurs only in the equatorial Pacific region, it could affect over more than 75% of the earth (Jones, 1988; Jiang et al., 2006). Many researchers have indicated that ENSO anomalies, in the equatorial eastern Pacific region, also have tremendous impacts on climatic patterns in China (Dong and Liu, 2000; Jiang et al., 2006). These include the effects on runoff in the upper reaches of the Yellow River (Lan et al., 2002). Generally low river flows are usually associated with El Niño events and floods usually accompany La Niña events in the Yellow River. By affecting such important abiotic variables, such as temperature, precipitation, and water quality, the ENSO phenomena can influence the growth, phenology and persistence of stream organisms on the Asian Continent (Vass et al., 2009).

Ecological effects of climate change on terrestrial and marine ecosystems have been studied extensively (Root et al., 2003; Rolim et al., 2005; Sellanes et al., 2007; Heinrich et al., 2009). Several studies report on aspects of meteorological and hydrological fluctuations in freshwater ecosystems (Zhang et al., 2005; Jiang et al., 2006; Keil et al., 2008), but few have explicitly linked them to biological changes. However, in Europe, America, and Oceania, several studies have ascribed long-term shifts in freshwater communities to directional climatic changes (Daufresne et al., 2004; Harper and Peckarsky, 2006; Durance and Ormerod, 2007; Haidekker and Hering, 2008; Chessman, 2009). However, very little information is available on the effects of climate changes on freshwater macroinvertebrate communities in Asia (Dudgeon, 2007; Vass et al., 2009). Thus, a case was quantitatively studied in the Xiangxi River watershed, within the East Asian monsoon region, to reveal the influence of climate change on macroinvertebrate communities in this region.

We believe that uninterrupted ecosystem monitoring of the Xiangxi River system is a good strategy for assessing climatic effects. There exist many published studies in this area that have focused on environmental variables and macroinvertebrates (Qu et al., 2005; Jiang et al., 2008; Li et al., 2009a, b). Our present study examines relationships between macroinvertebrate communities and climatic variables in the upper Xiangxi River, Central China, during winter. Our aims were: (i) to test the hypotheses that air temperatures increased, and water flows decreased, in response to global climate change; (ii) to test the hypotheses that there have been significant reductions in macroinvertebrate abundance and diversity related to climatic change and, (iii) to use regression and ordination models to predict future potential effects of shifting climate on metrics and species of stream macroinvertebrates.
2. Materials and Methods

2.1. Study area and sites setting

The present study was conducted in the Xiangxi River, the largest tributary flowing into the Three Gorges Reservoir (TGR) in Hubei province. This river is a 6th-order stream originating in the mountains of the Shennongjia Forest. The river flows 94 km and descends 1540 m before converging with the Yangtze River. This river drains a catchment covering 3099 km² with average annual precipitation of 900–1200 mm. The Gufu, Gaolan, and Jiuchong streams are the three main tributaries in the Xiangxi River watershed (Fig. 1) (Li et al., 2009b; Ye et al., 2009). The Jiuchong and the upper Xiangxi watersheds are covered with forests, whereas the Gufu and Gaolan watersheds are mainly dominated by farmlands. Four sites were used in this study, including Sites A and B on the Jiuchong stream and Sites C and D on the upper main stem of the Xiangxi River. All sites had similar altitudes (634–802 m), stream orders (2nd or 3rd), and relatively low anthropogenic disturbance. The adjacent sites were < 10 km apart.

pHs (8.29 ± 0.37), conductivities (245.86 ± 34.39 μS cm⁻¹), and concentrations of total dissolved solids (TDS) (149.83 ± 28.01 mg L⁻¹), total nitrogen (TN) (0.85 ± 0.35 mg L⁻¹) and, total phosphorus (TP) (0.03 ± 0.01 mg L⁻¹) in the study area were somewhat lower than at downstream sites.

2.2. Benthic macroinvertebrate sampling

Benthic macroinvertebrate sampling was carried out monthly in winter, from December to February, through six continuous years (2001–2007). However, owing to landslides, no samples were taken in February 2002 and January 2003. We sampled during winter for two main reasons: (1) winter conditions were predicted to be more sensitive to climate change (Thomas et al., 2004), and (2) macroinvertebrate assemblages were thought to show the maximum stability at this time after recovering from the preceding summer floods (Collier and Quinn, 2003).

A 0.42 mm mesh Surber sampler (sampling area = 900 cm²) was used to take samples for three times at different habitat types (i.e., riffle, run and pool) from a 100 m reach at each sampling site. All stones within the sampler frame were scrubbed with a soft brush to remove attached organisms. Unconsolidated
substrates were disturbed to a depth of about 10 cm and dislodged organisms were swept into the net by currents. Samples were then preserved in 10% formalin (HUANG et al., 2000), and all collected macroinvertebrates were identified to genus or species levels following KAWAI (1985) and MORSE et al. (1994).

2.3. Climatic data collection

Although measured water temperature data are available for each sampling time, we calculated water temperature from a regression model between water and air temperatures at site A. The air temperature data were from an automatic, continuous meteorological station at the town of Gufu (see Fig. 1). The air temperatures were more consecutive and comparable than the measured water temperatures. We used linear regression and calibrated the relationship between water and air temperatures by using data for more than seven years ($R^2 = 0.853; n = 349$). These included monthly data from July 2001 to October 2008 ($n = 88$) and daily data of 18th August 2008, 20th September 2008, and 28th October 2008 (the measuring interval is 15 minutes, $n = 261$). Regressive water temperatures were then used to assess the influence of temperature variation on macroinvertebrate assemblages.

Because there is only one hydrological station (Fig. 1), these data cannot be used for the sub-watersheds. Instead, watershed areas of the sampling sites, and the hydrological station site, were calculated using ArcGIS (version 9.2). Therefore, based on the area data, and the multi-year (1959–2007) average daily flow data, from the hydrological station, the water flow of each sub-watershed was calculated with the conversion method according to linear equation between the area and flow data (HÖRMANN et al., 2009). The regressive water flow was then used to assess the influence of flow variation on macroinvertebrate assemblages.

The sea surface temperature (SST), which reflected ENSO events, was obtained from the Climatic Research Unit at the University of East Anglia (UK) (http://www.cru.uea.ac.uk). This index is calculated from the difference of SST for the eastern Pacific region (90–180° W, 0–10° S) (JONES, 1988; JIANG et al., 2006). We parameterized the SST using the preceding 3-month running mean. This resulted in a smoothed sea surface temperature (SSST).

Average annual air temperature, average annual water flow and average annual SSST were then used to clarify the climatic trends from 1978 to 2007.

2.4. Data analysis

One-Way ANOVA did not significantly differ for temperature ($P > 0.5$), pH ($P > 0.5$), conductivity ($P > 0.5$), TDS ($P > 0.5$), TN ($P > 0.5$), abundance ($P > 0.5$), richness ($P > 0.5$), or the Margalef index ($P > 0.5$), between these four sites. Only the TP was an exception in this regard ($P < 0.05$). Thus, environmental variables, including water temperature (Fig. 2), and macroinvertebrate metrics (Fig. 3) of
these four sites were expected to be similar, and we could pool the temperature data at these four sites. Mean values were then calculated for these four sites to reduce the monthly variations. A total of 16 samples (n = 3 winter months × 6 years – 2 months with no samples) were defined for subsequent analysis.

Linear regression was applied to examine the trends of water temperature, water flow, and SSST over the last 30 years. Regression analyses were used to predict the relationships between climatic variables and macroinvertebrate metrics.

Testing hypothesis 2 required data on macroinvertebrate metrics from December 2001 to February 2007. This was normalized for total abundances (numbers of individuals per 1 m²) and richness (numbers of species per 1 m²), while diversity was assessed using the Margalef index, which was calculated as:

$$\frac{S - 1}{\log_2 N}$$

where S is the number of species in the sample, N is the total abundance in the sample.

We investigated patterns in multivariate benthic macroinvertebrate data using detrended correspondence analysis (DCA), a simple and flexible method of indirect ordination, and then related the scores of DCA to climatic variables. Regression equations relating DCA scores to climatic variables were used to predict the effects of climate change on macroinvertebrate communities. The optimum and tolerance of each species, to certain climatic variables, obtained from the DCA results, were used to indicate the sensitive or potential risk species to climatic variables. We assumed that species, with low optimal tem-

Figure 3. Annual means of the benthic macroinvertebrate metrics at four sites in the upper Xiangxi River from July 2001 to June 2007: (A) abundance, (B) richness and (C) Margalef index.
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peratures, may be more endangered under global warming scenarios, because global warming reduced the available optimal habitats for this species. The above analysis was performed by CANOCO for Windows 4.5 (LEPS and SMILAUER, 2003), with rare species down-weighted and relative abundances of the component taxa transformed before analysis.

Using regression analysis, we predicted the potential effects on macroinvertebrate metrics when the water temperature increased by 1 °C, the water flow decreased by 10%, and the SSST value increased by one unit over the current means in winter (DURANCE and ORMERO, 2007).

Table 1 Regression relationships (\(y = a + bx\)) between annual air temperature or water flow and study year in the upper Xiangxi River over the period 1978–2007.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Independent variables</th>
<th>(a) (SE)</th>
<th>(b) (SE)</th>
<th>(F)</th>
<th>(R^2)</th>
<th>df</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>Year</td>
<td>16.57 (0.17)</td>
<td>0.02 (0.01)</td>
<td>4.57</td>
<td>0.14</td>
<td>1,28</td>
<td>0.04</td>
</tr>
<tr>
<td>Water flow</td>
<td>Year</td>
<td>77.24 (6.35)</td>
<td>-1.03 (0.35)</td>
<td>8.16</td>
<td>0.23</td>
<td>1,28</td>
<td>0.01</td>
</tr>
<tr>
<td>SSST</td>
<td>Year</td>
<td>-6.14 (3.01)</td>
<td>0.11 (0.17)</td>
<td>0.39</td>
<td>0.02</td>
<td>1,28</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Figure 4. Variations of the annual air temperature (A), annual water flow (B) and annual SSST (C) in the upper Xiangxi River from 1978 to 2007. Fitted (least squares) linear regression lines are shown and regression equations can be found in Table 1.
3. Results

3.1. Climatic variations in the Xiangxi River watershed

Average annual air temperatures in the study watershed ranged from 16.0 to 17.8 °C from 1978 to 2007, increasing significantly \( (P < 0.05) \) by 0.2 °C/decade on average (Table 1, Fig. 4A). In contrast, average annual water flows ranged from 38.5 to 117.6 m\(^3\) s\(^{-1}\) during this period, decreasing significantly \( (P < 0.05) \) by 30.9 m\(^3\) s\(^{-1}\) on average (Table 1, Fig. 4B). There were no significant long-term temporal trends in the SSST (Table 1, Fig. 4C).

3.2. Relation between benthic macroinvertebrate assemblages and climatic variables

Benthic macroinvertebrate abundance, total richness, EPT richness, and Margalef index all had decreasing trends with increasing water temperature, in winter, over the last six years. The macroinvertebrate metrics increased with increasing SSST (Fig. 5). However, no relationships were found between the macroinvertebrate metrics and the water flow.

The winter macroinvertebrate abundance and the Margalef index fell by 11.1% and 6.8% for each 1 °C rise in water temperature. The relationships between climatic variables and biotic metrics were described in detail in Table 2. A direct relationship was shown between the scores of DCA axis 1 and the water temperature, and 28.3% of the variations in the composition of the community were explained by axis 1. Taxa characteristic of cooler phases included: *Cricotopus* sp., *Potthastia gaedii*, *Orthocladius clarkei*, *Dicranota* sp., *Hippeutis umbilicalis* and *Sinopsephenus* sp., whereas *Polypedilum* sp., *Oligochaeta* spp., *Rheopelopia* sp., *Bezzia* sp. and *Lithax* sp. were typical of warmer phases (Fig. 6A).

The SSST could explain 32%–54% of the variations in macroinvertebrate metrics across years (Table 2). A projected SSST shift of +1 unit is predicted to increase the abundance of winter macroinvertebrates, and the Margalef diversity index, by up to 38.2% and 16.0% of the current mean values (Table 2, Fig. 5B, H). The total richness will increase by 0.4 taxa as the SSST shifts from −1 to +1 (Table 2, Fig. 5D). Axis 4 of the DCA was positively related to the SSST, and 4.4% of the variations in the community composition, were explained by axis 4. The taxa associated with positive SSST years included: *Aethaloptera* sp., *Lype* sp., *Parapsyche* sp. and *Chaetocladius* sp., whereas *Potthastia gaedii*, *Cricotopus* sp., *Orthocladius luteipes*, *Brachycentrus* sp. and *Oligochaeta* spp. were characterized by negative SSST phases (Fig. 6B).

3.3. Future effects of climate on benthic macroinvertebrates

Using the regression equations we developed above, we determined the magnitude of change predicted to occur in different macroinvertebrate metrics with climate change. A future increase of 1 °C in water temperature is predicted to increase the scores of DCA axis 1 by 0.6 units (Table 2). This may lead to the potential local extinction of two taxa, *Orthocladius clarkei* and *Hippeutis umbilicalis*, because they tend to occur at narrow ranges of low temperatures (Fig. 6A).

A rise of one SSST unit could reduce the scores of DCA axis 4 by 0.3 units (Table 2). This could lead to the potential local extinction of four other taxa, *Potthastia gaedii*, *Cricotopus* sp., *Orthocladius luteipes* and *Brachycentrus* sp., which occur at narrower ranges of low SSST values. A reduction of one SSST unit could potentially result in the projected loss of other four taxa, *Aethaloptera* sp., *Lype* sp., *Parapsyche* sp. and *Chaetocladius* sp. (Fig. 6B).
Figure 5. Relationships between benthic macroinvertebrate metrics and water temperature (left) or SSST (right) in the upper Xiangxi River during the winters of 2001 to 2006: (A) water temperature – abundance, (B) SSST – abundance, (C) water temperature – total richness, (D) SSST – total richness, (E) water temperature – EPT richness, (F) SSST – EPT richness, (G) water temperature – Margalef index and (H) SSST – Margalef index. Fitted (least squares) linear regression lines are shown and regression equations can be found in Table 2.
Table 2  Regression relationships ($y = a + bx$) between scores of DCA axis and water temperature or SSST in the upper Xiangxi River during the winters of 2001 to 2006.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Independent variables</th>
<th>$a$ (SE)</th>
<th>$b$ (SE)</th>
<th>$F$</th>
<th>$R^2$</th>
<th>df</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance</td>
<td>Water temperature</td>
<td>8736 (2684)</td>
<td>–965 (501)</td>
<td>5.71</td>
<td>0.29</td>
<td>1,14</td>
<td>0.03</td>
</tr>
<tr>
<td>Richness</td>
<td>Water temperature</td>
<td>77.27 (19.28)</td>
<td>–4.66 (3.63)</td>
<td>1.75</td>
<td>0.11</td>
<td>1,14</td>
<td>0.22</td>
</tr>
<tr>
<td>EPT richness</td>
<td>Water temperature</td>
<td>34.94 (6.30)</td>
<td>–1.96 (1.19)</td>
<td>2.48</td>
<td>0.15</td>
<td>1,14</td>
<td>0.12</td>
</tr>
<tr>
<td>Margalef index</td>
<td>Water temperature</td>
<td>7.24 (1.29)</td>
<td>–0.49 (0.24)</td>
<td>4.67</td>
<td>0.25</td>
<td>1,14</td>
<td>0.05</td>
</tr>
<tr>
<td>Abundance</td>
<td>SSST</td>
<td>4287 (489)</td>
<td>1639 (818)</td>
<td>13.45</td>
<td>0.49</td>
<td>1,14</td>
<td>0.00</td>
</tr>
<tr>
<td>Richness</td>
<td>SSST</td>
<td>58.87 (3.87)</td>
<td>16.42 (7.02)</td>
<td>8.99</td>
<td>0.39</td>
<td>1,14</td>
<td>0.01</td>
</tr>
<tr>
<td>EPT richness</td>
<td>SSST</td>
<td>27.20 (1.16)</td>
<td>6.87 (2.11)</td>
<td>16.41</td>
<td>0.54</td>
<td>1,14</td>
<td>0.00</td>
</tr>
<tr>
<td>Margalef index</td>
<td>SSST</td>
<td>5.10 (0.27)</td>
<td>1.24 (0.50)</td>
<td>6.59</td>
<td>0.32</td>
<td>1,14</td>
<td>0.02</td>
</tr>
<tr>
<td>DCA 1 scores</td>
<td>Water temperature</td>
<td>–0.52 (0.47)</td>
<td>0.55 (0.28)</td>
<td>4.67</td>
<td>0.25</td>
<td>1,14</td>
<td>0.05</td>
</tr>
<tr>
<td>DCA 4 scores</td>
<td>SSST</td>
<td>0.43 (0.08)</td>
<td>–0.29 (0.10)</td>
<td>8.42</td>
<td>0.38</td>
<td>1,14</td>
<td>0.01</td>
</tr>
</tbody>
</table>
4. Discussion

Effects of directional climate change on stream macroinvertebrates, at this subtropical stream, have been studied. Results suggest that there were increases in air temperature and decreases in water flow in the upper Xiangxi River watershed from 1978 to 2007. The winter community abundance and diversity of macroinvertebrates dropped in association with increasing temperature over the last six years. This is in agreement with KLANDERUD and TOTLAND (2005) and DURANCE and ORMEROD (2007). However, except for some rare metrics, the links between metrics of macroinvertebrate assemblages and climatic variables are not so strong. If future effects were found to be consistent with the trends observed, a
continued global warming could lead to the disappearance of some taxa from the investigated area. Thus, depending on its strengths, the SSST can influence the compositions of stream organisms that are far away.

4.1. Water temperature and benthic macroinvertebrates

There were long-term increases in air temperature in the Xiangxi River watershed over the last 30 years (confirming our first study objective). This is in agreement with the results found in the upper Yangtze basin from 1950 to 2002 (ZHANG et al., 2005). The reduction in the community composition in relation to temperature increase is real (confirming our second study objective), because the effects of temperature on stream macroinvertebrate metrics will depend on complex interactions among thermal effects (ELLIOTT et al., 1988; CAISSIE, 2006). Rising water temperatures may increase the macroinvertebrate predation (KISHI et al., 2005), alter decomposition rates of leaf litter (LEPORI et al., 2005), and change algal production. Winter macroinvertebrate abundance might decline by 11.1\% for every 1 °C water temperature rise in the study streams, while higher losses (21\%) may be expected from stream macroinvertebrates in the British Llyn Brianne River (DURANCE and ORMEROD, 2007). The Margalef biodiversity in winter might be reduced by 6.8\% for every 1 °C water temperature rise in the study streams, while an approximate 30\% loss, in the diversity of macroinvertebrates, may be associated with the global warming. This has been observed in Canadian Jackfish and Murray lakes from 1930 to 2004 (SEREDA et al., 2011). Thus, compared with other studies, the effects of climate change on stream ecosystems are low in this area.

According to the DCA ordinations, several taxa were likely at the risk of extinction in the Xiangxi River watershed. This supports our third study objective. Taxa correlated to high temperature, including some dipterans and oligochaetes, might benefit from global warming, and increase their abundance and range of distribution. The number of individuals might decrease with global warming for some taxa belonging to dipterans and basommatophorans. We believe that macroinvertebrate taxa in the study streams may not be able to fly or drift to other close watersheds. This reflects the biogeographical isolation and habitat loss and fragmentation observed in this and other mountain ranges (MONAGHAN et al., 2005; LI et al., 2009a). Thus, although temperature increases in the study streams may allow some taxa to shift from lower to higher elevations, it is probable that some cold stenothermic macroinvertebrate taxa, such as Orthocladius clarkei and Hippeutis umbilicalis, may become locally extinct. Several other taxa have already been reported as locally extinct by MILNER et al. (2001) and ROSSARO et al. (2006).

4.2. Water flow and benthic macroinvertebrates

There were long-term reductions in water flow in the upper Xiangxi River over the last 30 years (confirming our first study objective), associated with decreases in precipitation and increases in temperature recorded in the upper Yangtze basin (ZHANG et al., 2005). However, no effects of water flow on benthic macroinvertebrate metrics were observed. This may be because: (1) benthic macroinvertebrates in these stony streams can get refuges during catastrophic flood events to decrease the lost influences (MORSE et al., 1994); (2) the effects of water flow were masked by water temperature or other variables; or (3) the water flow had a minimal effect on macroinvertebrate communities during some winter periods. However, if the water flow declines with the observed trend, some streams in the Xiangxi River watershed may stop flowing in a low flow period, and undoubtedly leading to marked impacts on stream communities (LI et al., 2009b). A significant increase in biotic variables, associated with the reduction of water flow, has already been observed in French Taillon-
Gabietous River (Brown et al., 2007). Additionally similar, but less pronounced, effects were also observed in the Llyn Brianne River in Britain (Durance and Ormerod, 2007).

4.3. Future effects of climate change on benthic macroinvertebrates

In projecting climate change effects on the biota in the Xiangxi River watershed, the relationships between SSST and biotic metrics, reached 32%–54%. This was more tightly related to biotic metrics than to water temperature (11%–29%), and perhaps is because the SSST effects on temperature and flow were more evident in summer. With the residual the long-term effects on the winter biota, this may reflect the preceding 3-month running mean. If so, the short-term relationships, between macroinvertebrate metrics and temperature or flow regimes in winter (Jiang et al., 2008), may be obscured.

Temperature and flow regions are related to large-scale atmospheric-oceanic oscillations, including ENSO, NAO (North Atlantic Oscillation), NPDO (North Pacific Decadal Oscillation), and AO (Antarctic Oscillation). The frequency and magnitude of these mid-term climate changes may be altered by global warming (Dong and Liu, 2000; Hurrell and Van Loon, 1997; Heinrich et al., 2009). Thus, these periodic climatic changes must be also considered in future studies, and their influences factored out, to examine the effects of long-term directional climate change on stream ecosystems (Dong and Liu, 2000; Jiang et al., 2006; Hurrell and Van Loon, 1997).

Diversities of animals and plants are extraordinarily high in tropical areas, especially in tropical rain forests. However, the reduction of biodiversity, from the equator to the poles, is one of the most pervasive features of nature (Wang et al., 2009). With the trends of global warming, the conditions and dynamics of temperature in subtropical regions will reach those in current tropical regions. This is expected to lead to the movement of species from tropical regions to subtropical regions or from lower mountains to higher elevations. A variety of studies have suggested this (Castella et al., 2001; Jablonski et al., 2006). Currently, stream macroinvertebrates occupy more isolated habitats, owing to natural or artificial barriers which block their migrations. Thus, stream communities in mountain areas are particularly vulnerable to losses in key taxa and biodiversity under the global warming (Brown et al., 2007; Durance and Ormerod, 2007). Long-term changes, in these ecosystems, may be related to the migration or expansion of stream organisms from tropical to subtropical regions or from lower to higher mountains. The immigration of warm-adapted species may increase the biodiversity.

In the early studies, metrics of benthic macroinvertebrates have been widely used as effective indicators for predicting hydrological or anthropological effects in stream ecosystems (Milner et al., 2001). The approach in our study is a novel indication of how stream macroinvertebrate communities could be used as indicators to study the effects of climate change. The optimal and amplitude temperatures, of benthic macroinvertebrates, provide the foundation for a novel biomonitoring approach to assess the extent of temperature increase in other close streams. However, our macroinvertebrate data are based on sampling in six continuous winters. It is possible that we have not encountered extreme flood or drought effects, so our extrapolations to future scenarios must be treated with caution.

We recognize that this 6-year study in the Xiangxi River provides only an initial evaluation of the vulnerability of subtropical stream benthic macroinvertebrates in mountain areas to climate change. However, it does illustrate the potential for using stream macroinvertebrates to help monitor the responses of ecological communities to climate change. Further detailed assessments of subtropical stream macroinvertebrate populations, and their relationships with climatic variables, are required to identify the risk species and to guide conservation and management strategies. In addition to broadening the spatial dimension, studies are required over longer time-scales to assess the effects of changes in climatic timing, as
well as their magnitudes discussed herein. Clearly, an extinction scenario for stream macroinvertebrates is undesirable in terms of biodiversity conservation. Hence, we represent the aquatic organisms and lend further weight to call for minimizing greenhouse gas emissions to reduce global biodiversity loss driven by climate change.

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